

Pentaquarks and the $X(3872)$ results from CDF¹

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Abstract

We report results of the searches for pentaquark states in decays to pK_S^0 , $\Xi^-\pi^\pm$ and $D^{(*)}p$ performed at CDF using 250 pb^{-1} sample of $p\bar{p}$ interactions at \sqrt{s} of 1.96 TeV. No evidence for narrow resonances was found in either mode. In addition, we present measurements of properties of the recently discovered $X(3872)$ particle.

¹This article goes to ICHEP04 Conference Proceedings.

1 Introduction

In this paper we will describe two topics presented at the ICHEP04 by the CDF Collaboration. The first one is the searches for exotic pentaquark states, discovery of which has been announced by other experiments over the last two years. The second topic is our study of the possibly exotic $X(3872)$ particle, discovered only a year ago.

Searches for states that can not be described from minimal two or three quark configurations have taken place since the introduction of the quark model. However the observations appeared only recently. The first one came from LEPS [1] in 2003, who observed a narrow resonance $\Theta^+ \rightarrow nK^+$ produced in $\gamma n \rightarrow K^-\Theta^+$. Soon after, a number of other experiments reported peaks in $\Xi^+\pi^\pm$, $D^{*-}p$ and other final states [2, 3]. The common feature to all these reports is that the states observed are most easily explained by five-quark configuration. The positive observations were followed by reports of non-observation from other experiments. The variety of available data are not exactly contradictory, as different experiments have different hadron production mechanisms and energies. Also the statistical significance of observed signals remains low and pentaquark characteristics vary significantly between experiments.

We report searches for several pentaquark signatures, taking advantage of the large CDF data sample and excellent detector resolution for narrow mass peaks. We reconstruct the primary expected signatures for Θ^+ , $\Xi^{--,0}$ and Θ_c pentaquarks decaying into charged particles.

On a separate subject, we report our studies of $X(3872)$, the particle that was discovered by Belle [4] last year and confirmed by CDF data a month after that. It is not clear at the moment whether it is an exotic particle such as $D\bar{D}^*$ molecule or simply a $c\bar{c}$ excited state with unusual properties. Experimental input on properties of the X is important to understand the nature of it. We present X mass measurements as well as lifetime fits in a sample of $X(3872) \rightarrow J/\psi\pi^+\pi^-$ decays that shed some light on X production at the Tevatron.

All of the results described in this paper have been obtained using data samples produced in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV and recorded with the upgraded CDF II detector at Tevatron, Fermilab.

2 Pentaquark searches

The data have been obtained through three types of triggers. The first dataset comes from the CDF hadronic trigger. This requires two oppositely-charged tracks with $P_T > 2$ GeV/ c displaced from the primary vertex by more than 0.1mm with the scalar sum of P_T values above 5.5 GeV/ c . The other two datasets come from the Jet20 trigger (calorimeter energy cluster with $E_T > 20$ GeV) and the minimum bias trigger (soft inelastic collisions). The data correspond to the total integrated luminosity of 250 pb $^{-1}$.

We reconstruct the expected pentaquark decay signatures as well as a number of well known reference decays. These are listed in Tables 1-4. Our reconstruction techniques are fairly standard, with optimal kinematic cuts and vertex fits of particle decay trees. It is worth mentioning our novel method of explicitly reconstructing Ξ^- tracks out of hits that the long-lived Ξ leaves in our silicon vertex detector. Particle ID requirements for slow protons help

Table 1: Reconstructed decays and signal yields for Θ^+ search and reference decays in Jet20 data.

resonance	yield
$\phi \rightarrow K^+ K^-$	26658 ± 385
$\Lambda \rightarrow p K^-$	4915 ± 702
$K^{*+} \rightarrow \pi^- K_s^0$	37769 ± 1390
$\Theta^+ \rightarrow p K_s^0$	< 76 @90% C.L.

Table 2: Reconstructed decays and signal yields for Θ^+ search and reference decays in minbias data.

resonance	yield
$\phi \rightarrow K^+ K^-$	19721 ± 273
$\Lambda \rightarrow p K^-$	3276 ± 327
$K^{*+} \rightarrow \pi^- K_s^0$	15695 ± 775
$\Theta^+ \rightarrow p K_s^0$	< 89 @90% C.L.

significantly to reduce backgrounds. In channels that involve $D^{*-} \rightarrow \bar{D}^0 \pi^-$ decays we use the standard technique of cutting on the mass difference between the D^{*-} and \bar{D}^0 candidates.

In all channels we observe no evidence for pentaquark states. Most of the reference signals have much higher statistics than anything reported by low energy experiments. Several examples of mass spectra are shown in Fig. 1-3 for Θ^+ and $\Xi^{--,0}$ pentaquarks. From the analysis of the mass distributions we derive upper limits on numbers of signal events for each of the searches. Our limits are summarized in Tables 1-4. For the $\Theta_c \rightarrow D\pi$ modes the uncertainty of the Θ_c mass adds another complication. For these modes we produce mass-dependent limits, varying the Θ_c mass from 3082 to 3116 MeV/ c^2 which is $\pm 3\sigma$ of Θ_c mass measurement by the H1.[3] An example of mass-dependent limit is shown in Fig. 4 for one of the modes. The limits for Θ_c quoted in the Table 4 correspond to the worst value observed in this $\pm 3\sigma$ mass range.

3 Studies of $X(3872) \rightarrow J/\psi \pi^+ \pi^-$

The data for this analysis have been collected using the $\mu^+ \mu^-$ trigger yielding a clean J/ψ sample. Kinematic and spatial cuts suppress large background from J/ψ combinations with random pions. The mass spectrum of $J/\psi \pi^- \pi^+$ candidates is shown in Fig. 5. A significant $X(3872)$ signal is observed. It is interesting to compare the mass spectra for $m_{\pi\pi} < 500$ MeV/ c^2 and > 500 MeV/ c^2 both of which are shown in the figure. No X-signal is apparent for the low $m_{\pi\pi}$, supporting Belle's observation of high-mass decays. Note the reference peak

Table 3: Reconstructed decays and signal yields for $\Xi^{--,0}$ search and reference channel in hadronic data.

resonance	yield
$\Xi(1530) \rightarrow \Xi^- \pi^+$	~ 36000
$\Xi^{--} \rightarrow \Xi^- \pi^-$	< 63 @90% C.L.
$\Xi^0 \rightarrow \Xi^- \pi^+$	< 144 @90% C.L.

Table 4: Reconstructed decays and signal yields for Θ_c search and reference channel in hadronic data.

resonance	yield
$N(D_2^{*0}) \rightarrow D^{*+} \pi^-$	6247 ± 1711
$N(D_1^0) \rightarrow D^{*+} \pi^-$	3724 ± 899
$N(D_2^{*0}) \rightarrow D^+ \pi^-$	34509 ± 1092
$N(D_2^{*+}) \rightarrow D^0 \pi^-$	13628 ± 813
$\Theta_c \rightarrow D^{*+} p$	< 21 @90% C.L.
$\Theta_c \rightarrow D^- p$	< 89 @90% C.L.
$\Theta_c \rightarrow \bar{D}^0 p$	< 87 @90% C.L.
$\Theta_c \rightarrow D^0 p$	< 97 @90% C.L.

of $\Psi(2S) \rightarrow J/\psi \pi \pi$ on the mass distribution.

Using the high $m_{\pi\pi}$ mass sample, we measure the X mass[5] to be

$$3871 \pm 0.7 \pm 0.4 \text{ MeV}/c^2.$$

This value is just above $D^0 \bar{D}^{*0}$ threshold, inviting speculations that the X is a $D^0 \bar{D}^{*0}$ molecule.

We have investigated the production of the X particle. The questions of interest are whether the X comes primarily from B meson decays at CDF and whether the direct production is different from that of charmonium. The technique of separating b decay feeddown from prompt sources is well established [6]. The X itself decays too rapidly to have a displaced vertex. X particles produced in b decays will be displaced due to the b lifetime. We measure the transverse displacement L_{xy} of X candidates and convert that into a pseudo-proper time $ct = M_X L_{xy}/p_T$. We fit the ct distribution with a prompt component and a long lived exponential convoluted with detector resolution plus an adequate background functional form. For events in the reference $\Psi(2S)$ peak we obtain the long lived component to be $28.3 \pm 1.0 \pm 0.7\%$. For the X events we measure it at $16.1 \pm 4.9 \pm 2.0\%$ (Fig. 6). Thus our X sample is primarily prompt with a modest b contribution. The production of X at CDF appears to be similar to that of $\Psi(2S)$.

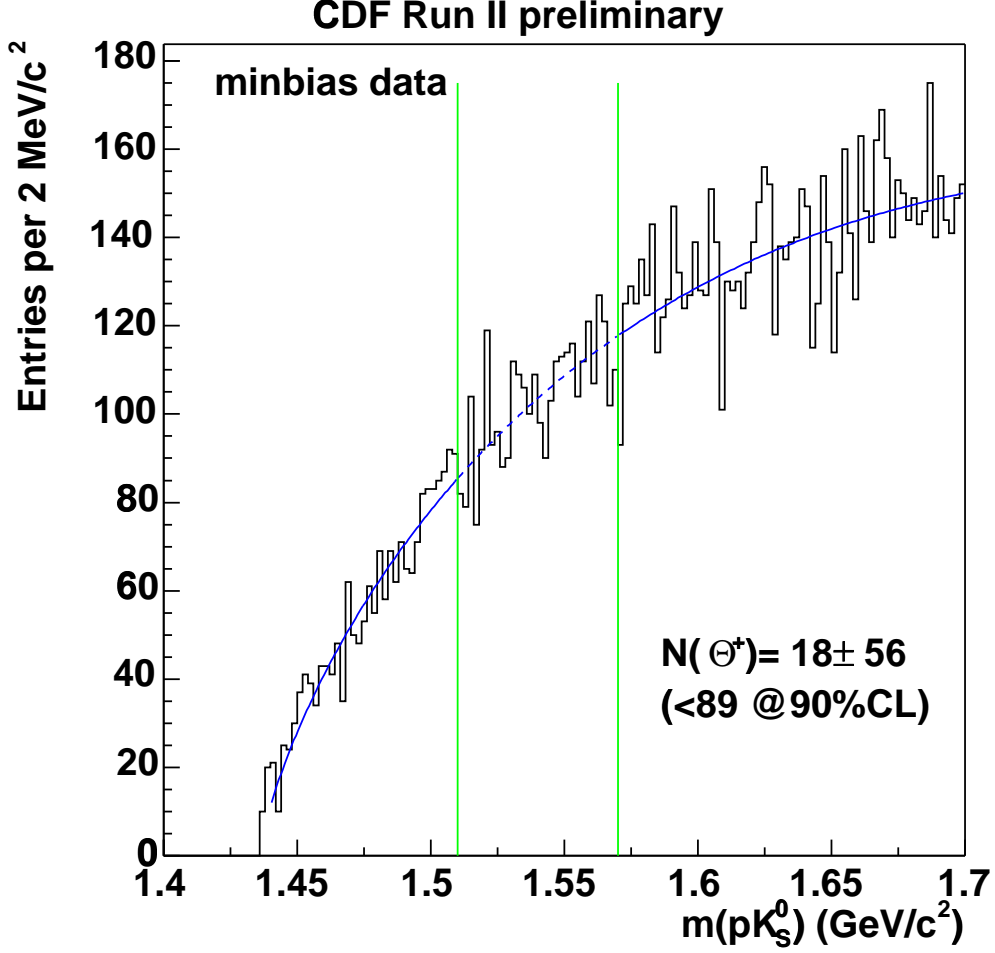


Figure 1: Invariant mass spectrum of $\Theta^+ \rightarrow pK_s^0$ from minbias data.

4 Conclusions

We observe no signal in searches for pentaquark states decaying into pK_s^0 , $\Xi^- \pi^\pm$ and $D^{*,-,0} p$. The high yields observed in reference channels demonstrate our sensitivity to such signatures and size of our data samples. The absence of the pentaquark signals suggests that production of pentaquarks, if they exist, is severely suppressed relative to more common particles.

For the $X(3872)$ we present a precise mass measurement and the measurement of the long-lived fraction in the signal that steps on the way to understanding the nature of the X .

References

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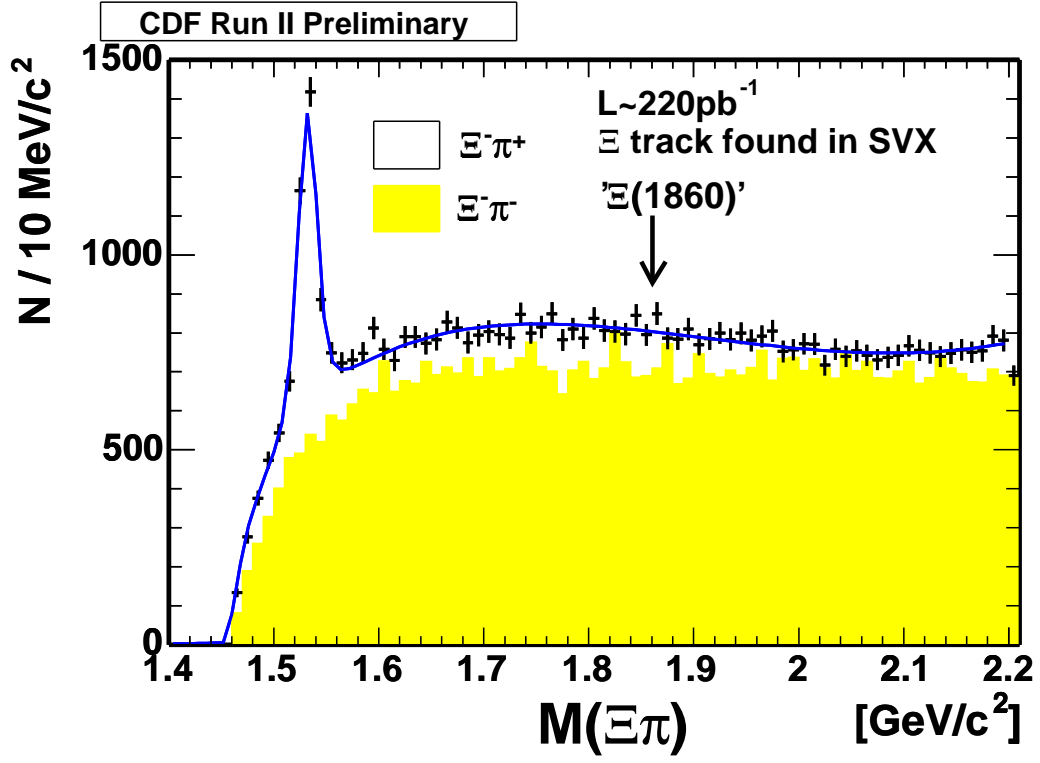


Figure 2: Invariant mass spectrum of $\Xi^{*-0} \rightarrow \Xi^- \pi^\pm$ from hadronic data.

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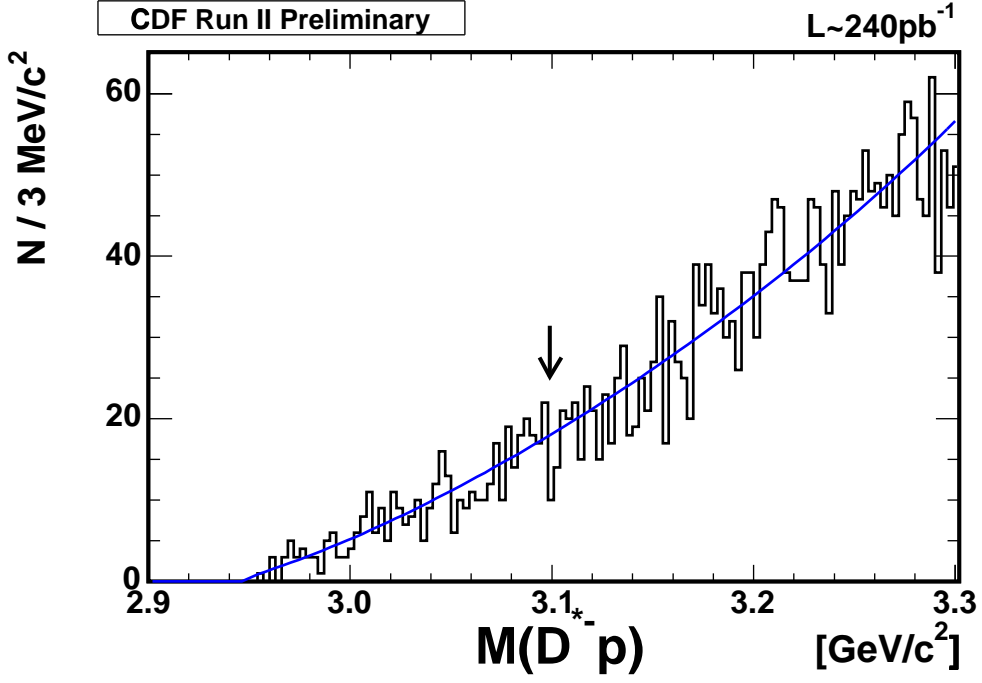


Figure 3: Invariant mass spectrum of $\Theta_c^0 \rightarrow D^{*-} p$ from hadronic data.

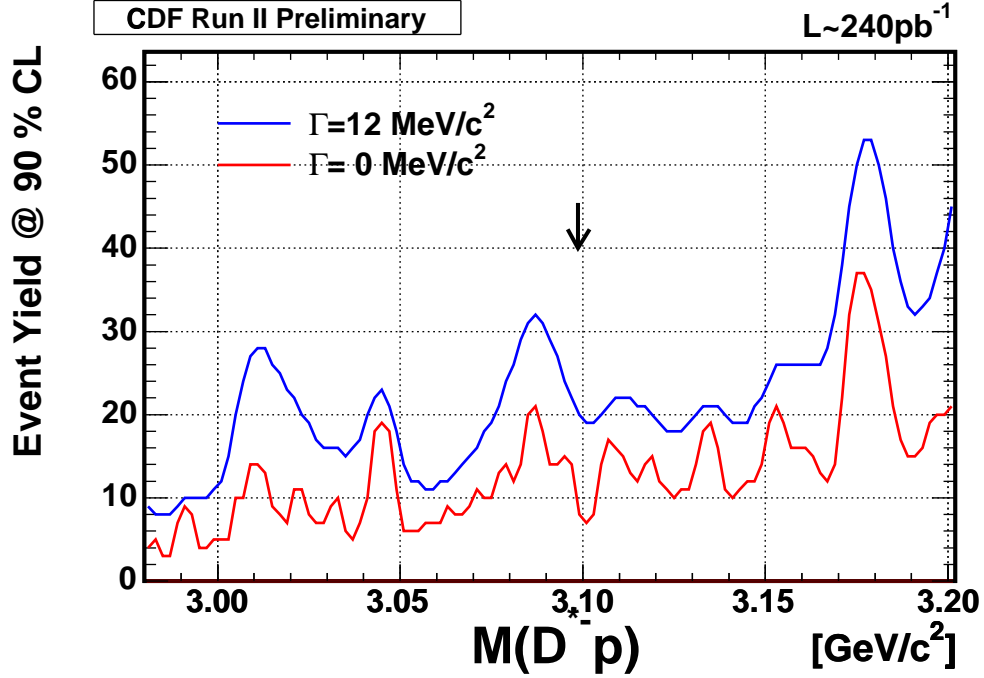


Figure 4: Mass dependent limit on the event yield for $\Theta_c^0 \rightarrow D^{*-} p$ from hadronic data.

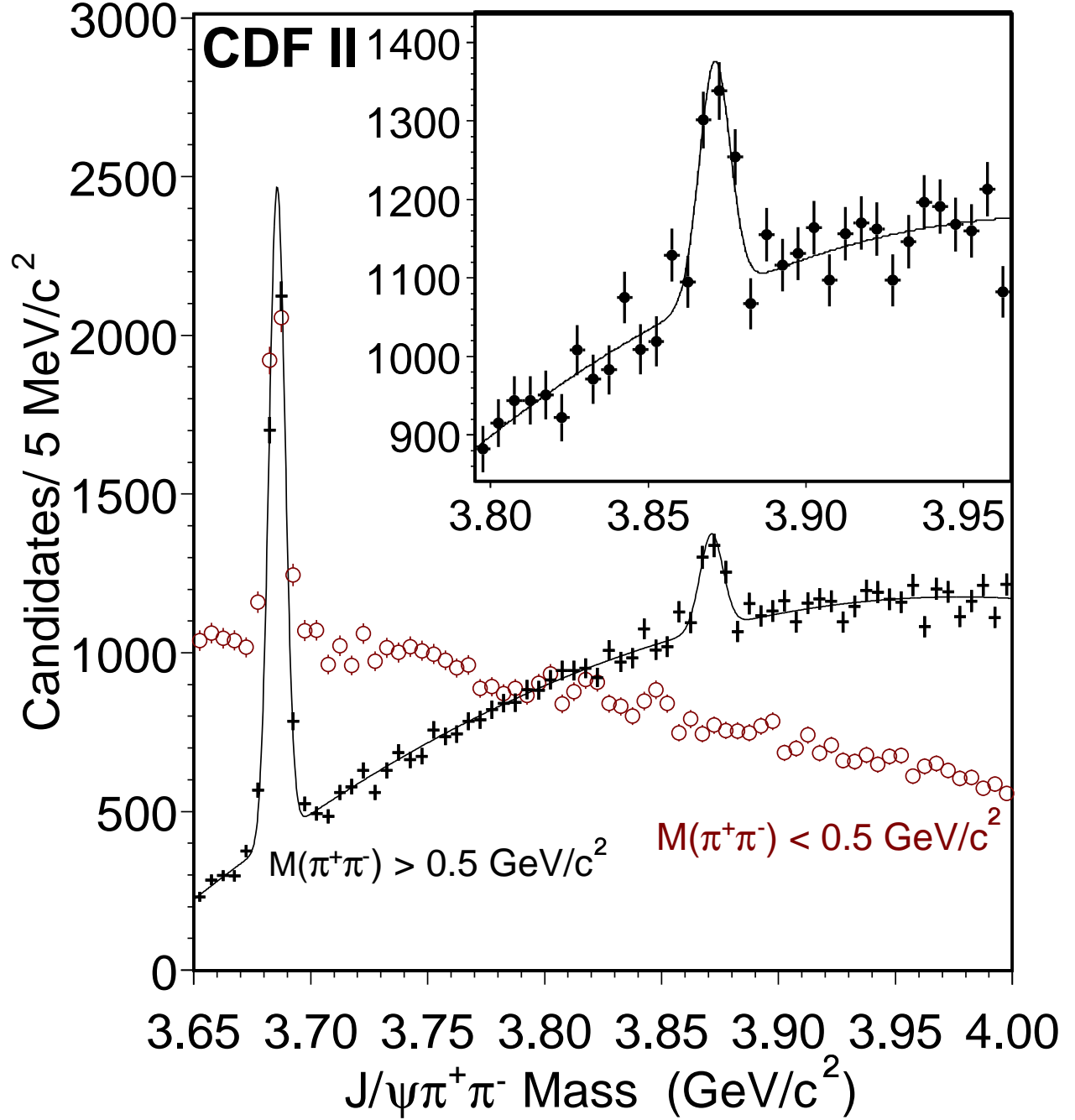


Figure 5: Invariant mass spectrum of $X(3872) \rightarrow J/\psi\pi^+\pi^-$ candidates.

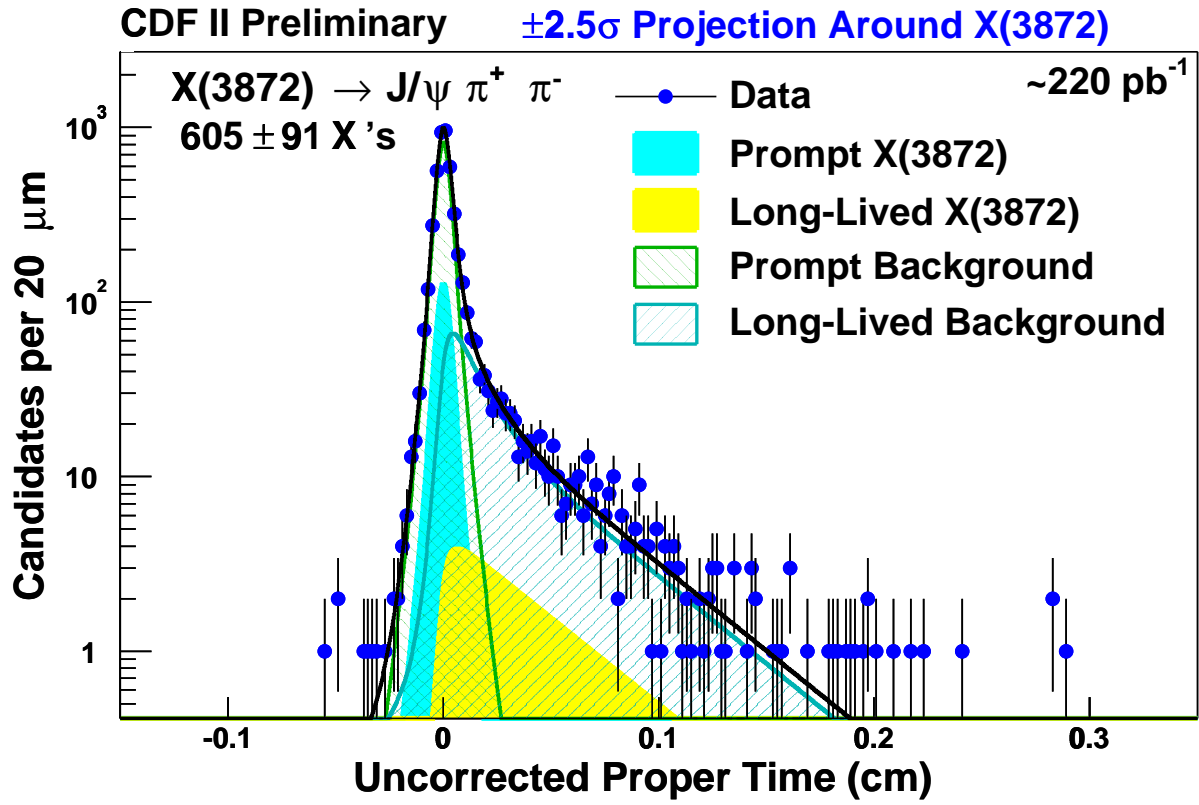


Figure 6: Pseudo lifetime distribution of $X(3872) \rightarrow J/\psi \pi^+ \pi^-$ candidates with the fit function fit overlaid.